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Analysis of Fabric Specimen Aspect Ratio and Deformation Mechanism during Bias Tension

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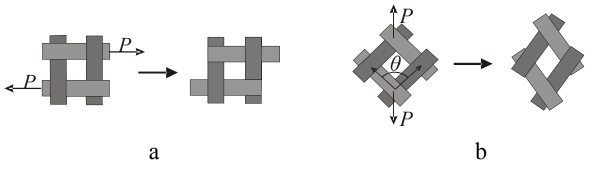
Different fabric specimen width/length ratios, called aspect ratios λ are used when bias extension method is applied for woven structure formability evaluation. The aim of this work was to study the influence of λ upon the parameters of fabric specimen's bias tension. Distinct deformation zones, shear angle and buckling wave propagations as well as critical form stability parameters (critical load P_{cr}, critical elongation ε_{cr} and critical shear angle γ_{cr}) were estimated to describe deformation mechanism of the specimen. The analysis of specimen deformations when aspect ratio $\lambda \geq 2$ has shown that with the increase of specimen's length critical form stability values also increase because of the increased strain distribution uniformity in a central part of a deformed specimen. The concentrated load method was applied in order to study deformation mechanism which is observed between two intersection points of distinct deformation zones without clamping impact. It was found that for longer specimens critical form stability parameters estimated during bias tension were similar to the parameters assessed at concentrated load method. Different specimen behaviour under concentrated load test has proved that the influence of all specimen zones upon critical buckling parameters during bias tension is significant.

Keywords: bias tension, concentrated load, buckling, fabric, formability, shear, specimen aspect ratio.

1. INTRODUCTION

As one of the most attractive engineering material fibrous materials in general and textiles in particular remain poorly understood. The fibre science has largely derived out of polymer science [1]. As many scientists prove the nature and behaviour of textiles is difficult and highly heterogeneous. This leads to challenging problems trying to create reliable and repeatable investigation method for the investigation of such material properties.

The behaviour of woven textile is mainly associated with orthogonal weave structure unit. This is the main reason for excellent formability due to relative movement of individual yarns in a fabric subjected to shear load. The yarns can reorient through sliding and slipping along the loading direction [1 – 3] (Fig. 1, b). The basis of shear mechanism is yarn rotation over crossover points that in many articles is presented as macro scale shear deformation (Fig. 1, a) [2 – 4].



a b

Fig. 1. Shear deformations of a fabric structural unit: a – yarn sliding mechanism, b – yarn rotation mechanism

Two different methods of woven structure formability properties investigation are widely presented. Shear properties as the main deformation mode during woven structure formation [2, 5, 6] are assessed by uniaxial bias tension and picture frame tests.

The advantages and drawbacks of these tests are studied until now and new ways to solve formability evaluation problems are still on the hunt.

The limitations of picture frame test are related to the specimen clamping procedure when both yarn systems of a fabric specimen are fixed in a frame arms and the same forces are applied upon warp and weft yarns. In a case of unbalanced fabric (tension properties of each yarn system are different) the obtained results will be inaccurate [6, 7].

During uniaxial tension the non-uniform deformations influence woven specimen due to clamping effect, and three distinct deformation zones can be distinguished in bias tensioned specimen [3 – 4, 6]. The pure shear zone is referred to be in a central part of a specimen where yarns are free of clamping. It is obvious that movement between two yarn systems in a central part is restricted by neighbouring zones where one or both yarn systems are clamped.

New method called concentrated load tension test was proposed by J. Amirbayat [8] for the investigation of woven structure properties in bias direction. Special clamping of specimen leads to avoid yarns fixing in clamps and high correlations are set between measured parameters during concentration load tension and fabric bending, shear and tension properties.

Widely applied uniaxial tension test currently is presented as the most advanced for fabric shear properties investigations during bias tension [3, 6]. The most important failures of bias tension test are related with specimen wrinkling or out-of-plane buckling problem when bias stretched specimen looses its form stability and no longer proper shear values can be measured.

Not only particular clamping but different specimen sizes are used to improve measurement of woven structure shear parameters. The proportions between specimen lengths to width is named specimen aspect ratio λ and

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throughout specific values of λ are found in scientific papers and standardised methods.

The standard LST EN ISO 13934 [9] is intended to evaluate fabric tensile properties in warp and weft directions when the specimen aspect ratio equals to $\lambda = 2$ or $\lambda = 4$. The aspect ratio $\lambda = 2$ when specimen size is 50 mm × 100 mm is used in widely employed FAST (Fabric Assurance by Simple Testing) system [10] for fabric quality control and assurance. The American standard ASTM D1774-93 [11] for the investigation of elastic properties of textile fibres refers to bias tension test when specimen size is 75 mm × 200 mm, i. e. $\lambda = 2.66$.

To obtain a uniform shear deformation zone, the aspect ratio is defined to be greater than 2 though commonly used aspect ratio of a specimen is $\lambda = 2$ [3, 7] and $\lambda = 2.66$ [6]. Also it was found [4] that for woven specimens $\lambda = 3$ were used. Radko Kovar et al. have analyzed the influence of bias cut specimen size upon the strength characteristics of the sample. Specimens of aspect ratios $\lambda = 1.3$ and $\lambda = 4.0$ were studied in this paper [12].

The aim of this work was to evaluate the influence of woven specimen size upon the parameters of bias tension. Different bias cut (45° to the warp yarns system) specimen width/length variations with aspect ratios $\lambda = 1, 2, 3$ and 4 were used during conventional bias tension and concentrated load tension experiments. Distinct deformation zones, shear angle and buckling wave propagations, as well as, critical form stability parameters were estimated to describe deformation mechanism of a specimen during bias tension.

2. METHODS OF INVESTIGATION

The commercially available plain woven cotton fabric (Table 1) applicable in clothing industry was chosen for the investigations.

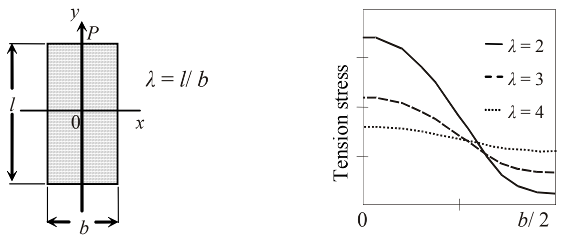
Table 1. Characteristics of tested fabric

Area density, g/m^2		72.00
Thickness, mm		0.28
Number of threads per unit length, cm^{-1}	warp	30
	weft	18
Linear density, tex	warp	13.50
	weft	13.40

During tension test the stress and strain distribution along the direction of applied load is non-uniform and dependences of stress and solid plate aspect ratio are known (Fig. 2) [8]. To analyse the effect of specimen's aspect ratio upon the parameters of tension deformation two uniaxial tension test methods – bias tension and concentrated load tension (Fig. 3) were performed by a universal tensile testing machine. Nine rectangular specimens cut at the 45° angle of to warp yarn system were prepared for each test session.

For the investigations specimens with operating area of (100 × 100) mm^2, (50 × 100) mm^2, (50 × 150) mm^2 and (50 × 200) mm^2 were cut. Aspect ratio respectively varied from $\lambda = 1$, $\lambda = 2$, $\lambda = 3$ to $\lambda = 4$. For the bias tension the specimen was fixed throughout all width in clamps of a machine (Fig. 3, a).

During the concentrated load experiment the specimens were clamped using a special punch attachment avoiding yarn damages in fabric specimen centre 10 mm from sample ends (Fig. 3, b). The specimens with operating area of (50 × 50) mm^2 and (50 × 100) mm^2 (aspect ratio $\lambda = 1$ and $\lambda = 2$ respectively) were tested. The test of concentrated load was performed without bending movement restriction of clamped samples.



a b

Fig. 2. The distribution of axial (tension) stresses within rectangular solid plate (a) cross-section under concentrated tension load (b)

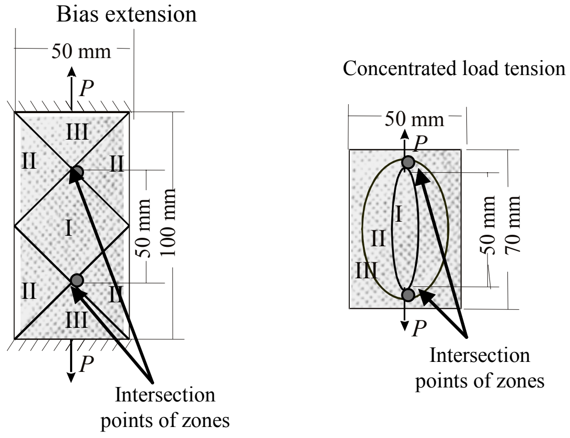


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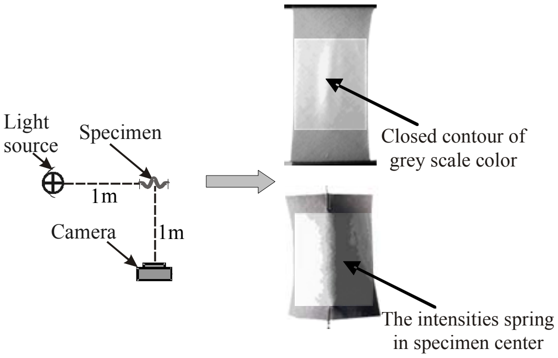
Fig. 3. The specimen clamping conditions and distinct deformation zones separated in a specimen with aspect ratio $\lambda = 2$ (a) and $\lambda = 1$ (b)



a b

Fig. 4. Test arrangement for image capturing (a) and principle of image analysis (b) to commit buckling moment

During both tests behaviour of the bias specimen was analysed at maximum force and at low loads, i. e. 50 N/m.

The special illumination arrangement (Fig. 4) was applied for image analysis evaluation in order to commit the moment when the stretched specimen looses its stable form and starts to buckle. Images of the specimen deformation at every step of 0.5 mm were recorded. The buckling moment was defined from captured digital images of 256 grey scale values after several steps of image filtering [13, 14] and described by such parameters as: critical load P_{cr}, critical elongation ε_{cr} and critical shear angle γ_{cr}.

The main zones with different modes of deformation were identified tracing the last clamped yarn (Fig. 5). The angle θ between two yarns systems was evaluated in all specimen deformation zones. From 5 up to 9 measurements of angle θ were performed for each separated zone and mean value of angle θ was calculated. Shear angle γ was defined as $\gamma = \pi/2 - \theta$. The coefficient of variation of measurements varied up to 4.92 %.

3. RESULTS AND DISCUSSION

Tensile characteristics of the tested fabric are presented in Table 2. When specimen aspect ratio is equal or higher then 2 maximum force P_{max} and maximum elongation ε_{max} the values are approximately the same. But in the case of $\lambda = 1$ significant decrease of these characteristics is registered.

Table 2. Tensile characteristics of tested fabric

Aspect ratio λ	Maximum force (P_{max}), N/m	Maximum elongation (ε_{max}), %	Initial slope angle (tgα)
1	344	11.54	3.89
2	529.5	36.60	0.59
3	510.3	36.50	0.65
4	522.6	38.18	0.59

The investigations of different deformation mechanisms during bias tension, when aspect ratio of a specimen is changed, are presented in the next sections of this chapter.

3.1. The study of deformation mechanism of specimens when aspect ratio $\lambda \geq 2$

During bias tension test when the specimen aspect ratio was different, the deformation zones with distinct proportions were identified (Fig. 5). When specimen length increases the areas of II and III zones remain without changes and only the area of I zone increases. This indicates the increase of region where pure shear deformation reveals because of yarns rotation over crossover points. II and III zones restrict yarns movement in a zone I but in the case of longer specimen this impact is declining.

The obtained tension curves P–ε with estimated critical form stability points are presented in Figure 5. The specimen critical buckling parameters are listed in Table 3.

According to the presented results critical form stability values increase when specimen length increases and the linear relationship between the measured critical buckling parameters can be established (correlation coefficients are 0.99 ÷ 1.00). Buckling phenomenon of a stretched bias specimen is related with axial stress and strain distribution in a specimen cross-section (Fig. 2).

It is obvious that in bias tension strain distribution in fabric specimen is highly non-uniform due to distinct deformation zones propagation. More uniform strain distribution in a specimen centre zone I and lower values of strain between two intersection points of distinct deformation zones are determined with increase of specimen length [7, 8]. The intersection of three distinct deformation zones in a deformed specimen can be identified as stress concentrator and buckling wave is formed between these two points (Fig. 3). The largest strain takes place in a middle part of a specimen. Strain values are decreasing from specimen middle to the cut edges [3, 8].

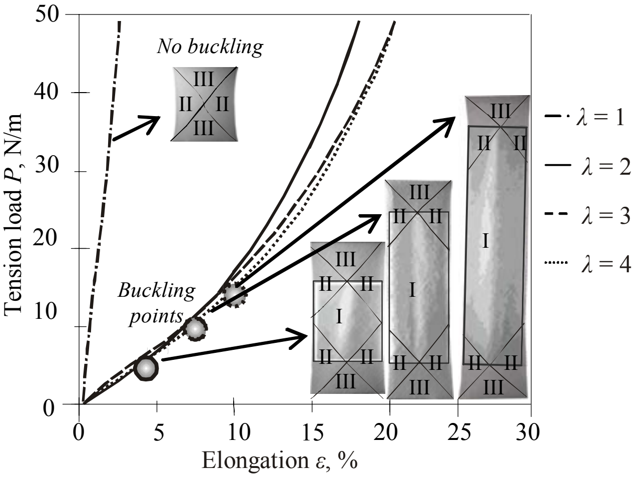


Fig. 5. The curves of bias extension at low loads and the views of specimen buckling moments

Variations of shear angle γ in three distinct deformation zones during fabric specimen tension are presented in Figure 6 as P–γ curves. The influence of fabric specimen aspect ratio to shear angle variation wasn't well-defined though increase of P–γ curves linearity for longer specimens was observed. This confirms the above presented discussion about strain distribution uniformity increase in the case of longer specimens.

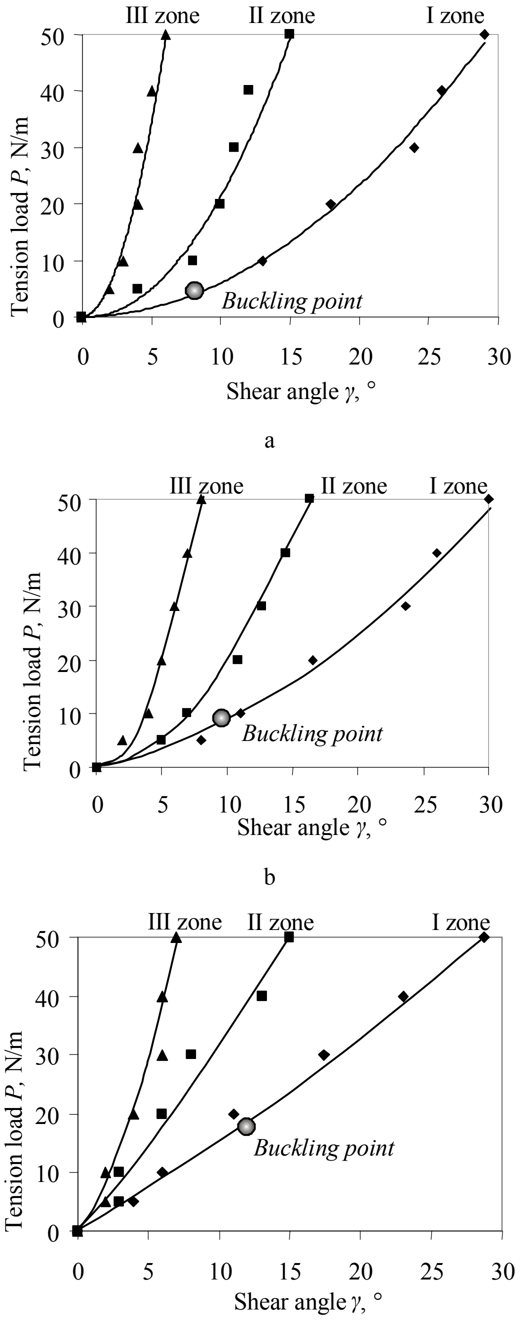
Table 3. Critical buckling conditions for the stretched bias samples

Aspect ratio λ	Critical load (P_{cr}), N/m	Critical elongation (ε_{cr}), %	Critical shear angle (γ_{cr}),°
2	7.06	5.1	8
3	10.09	7.0	10
4	13.23	10.0	12

Regardless to the critical shear angle value increase when specimen aspect ratio increases (Table 3) during continued tension specimens have reached approximately the same shear angle γ values in all zones (Fig. 6).

3.2. The study of deformation mechanism of specimens when aspect ratio $\lambda = 1$

Only two distinct deformation zones can be separated in a specimen with aspect ratio $\lambda = 1$. There is no zone I in the case of these specimens and only one intersection point



a

b

c

Fig. 6. Shear angle γ variation when specimen aspect ratio is changed: $\lambda = 2$ (a), $\lambda = 3$ (b) and $\lambda = 4$ (c)

can be identified between two zones. No critical form stability parameters were estimated because the form and nature of buckling was different. The increase of shear angle in zones II and III is presented in Figure 7. The shearing of yarns is obtained mostly because of yarns sliding mechanism because all yarns are fixed in the clamps and there is no zone where shear of non clamped yarns rotation over crossover points can occur during bias tension. The measured shear angle values are significant lower in comparison with the results obtained in the cases of specimen aspect ratio $\lambda \geq 2$. This kind of shear deformation is typical more for solid sheet materials and in textile science is called weft/warp shear [10, 15]. Deformation due to yarns sliding is dominant in products where fabric spatial shape is obtained because of biaxial tensile stresses aligned nearly orthogonal warp and weft yarns directions (for example in a inflatable fabric structures).

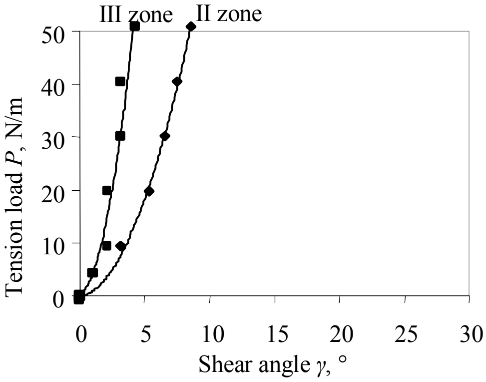


Fig. 7. Variation of shear angle in specimen when aspect ratio is $\lambda = 1$

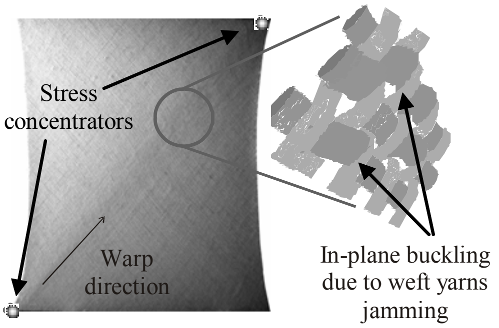


Fig. 8. The view of deformed specimen when one yarns system is significantly stretched and other one is jammed

The analysis of structural changes during bias tension has shown particular deformations obtained in a specimen weft and warp directions (Fig. 8). The woven fabric structure and different yarn count in warp and weft direction determine that warp yarns will be stretched more intensive then weft yarns near the clamps. The largest stresses raises near the clamps and they are different for each yarn system. Due to tension load lateral compression forces arise and warp yarns are jammed closer each other. Therefore crimp ratio of them increases until critical deformations are reached. According to references [2, 16] when critical deformations exceed and the gap between two yarns systems is closed, buckling deformation occur in a deformed fabric specimen. But in the case of $\lambda = 1$ aspect ratio regardless of lateral compression, fabric specimen doesn't loses its stable form and only buckling of weft yarns is observed, i. e. in-plane buckling occurs due to weft yarns jamming.

3.3. The study of deformation mechanism during concentrated load test

In order to overcome the limitations of conventional bias tension test, the investigation under concentrated load tension, that allows to avoid the influence of specimen clamping zones on form stability parameters of a fabric, were performed. During the experiment free action of all deformation modes (tension, shear, bending), which can occur during woven fabric forming process, was allowed. The deformation mechanism between two intersection points of distinct deformation zones of a bias tensioned fabric specimen was studied without clamps impact.

The obtained P–ε curves (Fig. 9) show different behaviour of the fabric specimens with aspect ratio $\lambda = 1$ and $\lambda = 2$ comparing with the bias tension of specimens with aspect ratio $\lambda = 2$ and $\lambda = 3$, respectively, when the same distance between the intersection points of zones is obtained (Fig. 3). During the bias tension almost the same tensile properties of a fabric were obtained in the case of $\lambda \geq 2$. Meantime concentrated load experiment shows the differences of fabric tension stiffness when the specimen aspect ratio is changed. The initial slope angle of a curve P–ε was obtained tg$\alpha = 0.24$ and tg$\alpha = 0.65$ when specimens aspect ratio was $\lambda = 1$ and $\lambda = 2$, respectively (Fig. 9). Specimen clamping and different shape of the distinct deformation zones can explain fabric behaviour during concentrated load test (Fig. 3).

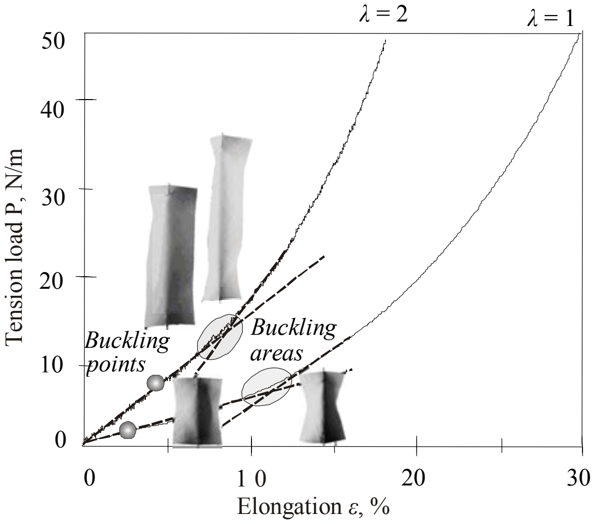


Fig. 9. The P–ε curves obtained during concentrated load experiment and the buckling moment estimation using tangent line techniques

Nevertheless the tensile curves (Fig. 5, Fig. 9) and critical form stability parameters (Table 3 and Table 4) of longer specimen when aspect ratio was 2 have shown similar behaviour of a fabric under bias and concentrated load tension.

Table 4. Critical buckling conditions of a specimen during concentrated load test

Aspect ratio λ	Critical load (P_{cr}), N/m	Critical elongation (ε_{cr}), %	Critical shear angle (γ_{cr}),°
1	1.89	2.5	5
2	7.91	4.5	8

The load-shear angle curves (Fig. 10) have shown the same tendencies as P–ε curves during the concentrated load bias tension. When specimen aspect ratio increases lower shear angle values are obtained, though in the case of $\lambda = 2$ the curve P–γ is more linear and it describes more uniform strain distribution in the specimen cross-section during concentrated load deformation.

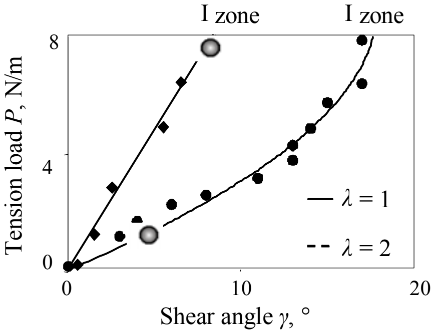


Fig. 10. The shear angle variation in a specimen zone I during concentrated load tension

The buckling moment of a deformed specimen was estimated using two techniques – image analysis [13, 14] and drawing tangent lines [8] of a tension curve that help to identify distinct regions of a specimen stiffness changes during deformation process (Fig. 9). It was observed that image analysis technique identifies specimen buckling earlier than tangent lines method, i. e. stretched specimen of a fabric buckles before deformation limit, i. e. before gap between yarns is closed. This fabric buckling phenomenon was analysed in an article [17].

4. CONCLUSIONS

1. Tensile properties (maximum force P_{max} and maximum elongation ε_{max}) of bias fabric specimen when aspect ratio is equal or higher then 2 were obtained approximately the same. When the specimen aspect ratio was $\lambda = 1$ values of the tensile characteristics P_{max} and ε_{max} were estimated significantly lower though the tension stiffness of these specimens has increased (tgα increased from 0.59 to 3.89).
2. The detailed analysis of deformation mechanism during bias specimen ($\lambda \geq 2$) tension has shown that critical form stability values increase when specimen length increases because of more uniform strain distribution in a central part of deformed specimen. The linear relationship between critical form stability parameters and specimen length was established (correlation coefficient 0.99 ÷ 1.00).
3. Buckling takes place between two intersections points of distinct deformation zones (I, II, III). These points can be described as stress concentrators. Variant fabric behaviour during concentrated load test when clamping impact is minimized has proved that under bias tension influence of all specimen zones upon critical buckling parameters is significant.
4. The obtained critical buckling parameters of a stretched specimen have shown that deformed fabric specimen buckles earlier in the case of short specimen because of neighbouring zones influence. Longer specimens ($\lambda = 4$) are proposed to employ for the shear angle evaluation during bias tension of woven structure.
5. The main deformations during bias tension of specimen when aspect ratio $\lambda = 1$ were obtained because of yarns sliding mechanism. Zone I and critical form stability parameters weren't committed for the specimens of this geometry. Only in-plane

buckling of yarns was observed when critical deformations were reached due to yarns jamming.

6. During concentrated load test changes of fabric, tension stiffness were observed when specimen aspect ratio was changed (tgα = 0.24 for λ = 1 and tgα = 0.65 for λ = 2). It was found that for longer specimens critical form stability parameters estimated during bias tension were similar to the parameters assessed at concentrated load method.
7. Lower load is required to obtain the same value of shear angle under concentrated load method then bias tension. Specimen clamping peculiarities, size and shape of distinct deformation zones explain fabric behaviour during concentrated load test.

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